Campbell 2 f 2 (1-21)

Bound Jul. 1884.

J. F. Campbell
Niddry Lodge
Kensington
London W.

With the Authors Compts

answered Sept 8. 1883.
Started the Crack business

OSCILLATION OF THE EARTH'S CRUST.

[*Extracted from the* GEOLOGICAL MAGAZINE, July and August, 1883.]

TRÜBNER & CO., 57 and 59, Ludgate Hill, London.

[*Extracted from the* GEOLOGICAL MAGAZINE, Decade II. Vol. X.
July and August, 1883.]

ON ACCUMULATION AND DENUDATION, AND THEIR INFLUENCE IN CAUSING OSCILLATION OF THE EARTH'S CRUST.

By CHARLES RICKETTS, M.D., F.G.S.

NO fact in Physical Geology is more frequently recorded than a simultaneous occurrence of subsidence of the earth's crust where deposition of sedimentary strata has been in progress. Reference is often made to the fact that the basement beds of different sedimentary formations were deposited in shallow water, and to the indications presented by subsequent deposits that they were accumulated in a sea of moderate depth. On them immense accumulations may have been deposited in successive strata, amounting even to miles in thickness; showing that with the deposition there has been a corresponding depression of the original surface. Though these phenomena are so inseparable in their occurrence and so well known, English geologists, until the last few months, have made little, it may even be said no endeavour, to determine whether they should be associated as cause and effect. This has not been the case with American geologists.

In 1859 Professor James Hall of the United States determined that "the removal of large quantities of sediment from one part of the earth's crust, and its transportation and deposition in another, would produce oscillation of level. When these are spread along a belt of sea-bottom, the first effect of this great augmentation of matter would be to produce a yielding of the earth's crust beneath, and a gradual subsidence would be the consequence." He founded this opinion on the results of an examination of Palæozoic strata along the Appalachian chain, of which strata the Carboniferous formation alone reaches to a thickness of 14,000 feet. It is evident "that the depth of the sea was not originally so great as the thickness of these accumulations, and the occurrence of ripple marks, marine plants, and other conditions prove that the sea in which these deposits were made was at all times shallow or of moderate depth."[1]

In North America it is so generally accepted that the phenomena of subsidence and accumulation are dependent the one upon the other, that Captain C. E. Dutton of the United States Ordnance Survey considers that "few geologists question that great masses of sedimentary matter displace the earth beneath them and subside."[1] This statement by Dutton cannot refer to geologists on this side of the Atlantic, by whom, it may be said, the subject has hardly been taken into consideration.

---

[1] Palæontology of New York, vol. iii., Introduction. An account of Professor Hall's opinions is given in Chemical and Geological Essays, Essay V., by T. Sterry Hunt, LL.D., F.R.S.

Sir John Herschel, in a letter to (Sir) Charles Lyell, dated 1836, made slight allusions to the effect which "the transfer of pressure from one part of the earth's surface to another would have on the fluid or semi-fluid matter beneath the outer crust." He supposed that "if the whole floated on a sea of lava, there would merely be an almost infinitely minute flexure of the strata."[2] He subsequently (in 1859) showed that "the bed of an ocean supported on a yielding substratum may be depressed, without a corresponding depression of its surface, by the simple laying on of material;"[3] and in a popular lecture illustrated the consequences resulting from the increase of pressure in one place and relief in others by what would occur to a ship floating even on her keel. "If the weight on the starboard be transferred to the port side, she will heel over to port; so if the continents be lightened, they will rise; if the bed of the sea receives additional weight, it will sink."[4] The theory did not receive such attention as was due to the great authority from whom it emanated; perhaps because the illustrations advanced did not afford sufficient or conclusive proof.

In the Geological Record for 1877 (p. 173) a French geologist is stated to regard the increasing weight of deposits in areas of subsidence as the chief factor of geological change.[5]

Besides these authors, no one having authority such as would influence geological opinion has, until within the last few months, considered the subject, though the records of the simultaneous occurrence of accumulation and subsidence are almost innumerable. Those who have watched the progress of geology must with Darwin "have been surprised to note how author after author, in treating of this or that great formation, has come to the conclusion that it was accumulated during subsidence;"[6] and it appears to me equally as great a wonder that so little endeavour has been made by these authors to determine whether the two classes of phenomena should be associated as cause and effect.

Mr. J. Starkie Gardner, F.G.S., in the GEOLOGICAL MAGAZINE for June, 1881,[7] and the Rev. Osmond Fisher, F.G.S., in his book entitled "Physics of the Earth's Crust," 1881, have commented on the occurrence of subsidence during the deposition of the different geological formations; and also where accumulations are in progress at the present time under the sea; or on land covered with a heavy load of snow, as in Greenland. They agree with me in considering the depression as the result of and caused by the weight of the accumulations. (I must express how greatly I feel indebted to these authors for the courtesy with which they have recognized such deductions made by myself as far back as 1865,[1] and more especially at various periods since 1871.[2]) They agree with me in considering the depression as the result of and caused by the weight of the accumulations. Mr. Fisher considers "it requisite for the explanation of the phenomena that there be a liquid, or at least a plastic substratum for the crust to rest on; nor is it easy to explain the sinking of areas in proportion to their becoming overloaded with sediment upon any other supposition; but if such a liquid substratum be granted, many of the facts are more easily explained. If the present configuration of the Himalayan region be one of approximate equilibrium, if much sediment be brought off the mountains and spread over the plains, the mountains must become after a while too light and the plains too heavy; and accordingly the mountains rise and the plains sink to restore the contour"[3] (or equipoise).

---

[1] The Geological History of the Colorado River and Plateaus, *Nature*, vol. xix. 1879, p. 251.

[2] Proceedings of the Geological Society, vol. ii. p. 548.

[3] Physical Geography, by Sir John F. W. Herschel, Bart., F.R.S., etc., § 132.

[4] About Volcanos and Earthquakes, Familiar Lectures, Lecture I. p. 11.

[5] V. H. Hermite, Sur l'unité des forces en Géologie, *Compt. Rend.* t. lxxxiv. pp. 459-461, 510-512.

[6] On the Origin of Species, by Charles Darwin, F.R.S., chap. ix., third edition, p. 313.

[7] Subsidence and Elevation, and on the Permanence of Continents, GEOL. MAG. Dec. II. Vol. VIII. p. 241.

It is now almost universally acknowledged that valleys have been excavated by subaerial agencies, and that the materials which once filled up the vacancies have been removed by rain and rivers, and carried down and deposited near the mouths of their respective rivers and neighbouring parts of the sea. Towards the mouths of large rivers every one knows the bottoms of the valleys are filled with detritus brought down by the stream; these deltoid accumulations being often not only of great width, but also of very considerable thickness. According to Sir Charles Lyell,[4] the thickness has been proved by borings to be more than 630 feet in the case of the Mississippi; but he considers it probable that it may have attained to twice or thrice that thickness; in the case of the Ganges, the depth reached was 481 feet; and in the Po 400 feet; each example afford-

[1] A Ramble in Shropshire, Proc. Birkenhead Lit. and Scient. Soc. 1865; A Wooden Implement found in Bidston Moss, Proc. Liverpool Geol. Soc. 1865-66.

[2] President's Address, by Charles Ricketts, Proc. Liverpool Geol. Soc., Session 1871–72. Also an abstract of the same, entitled "On Subsidence as the Effect of Accumulation," Geol. Mag. Vol. IX. p. 119, etc.

[3] Physics of the Earth's Crust by the Rev. Osmond Fisher, M.A., F.G.S., p. 83. Referring to the Himalayan region, it was stated by myself in 1875, when replying to objections which had been raised, that the removal by denudation of those portions of the mass which once filled up the spaces now forming the valleys and passes of this great mountain range, must have diminished proportionately the amount of weight pressing upon the fluid substratum. Should the sediment brought thence by the Ganges and Brahmapootra, and deposited in the Bay of Bengal, cause subsidence by its weight, it follows that the area from which the sediment has been derived must rise in proportion to the amount of material removed.—The Cause of the Glacial Period, by Charles Ricketts, Geol. Mag. Dec. II. Vol. II. p. 574, foot-note.

[4] Principles of Geology, vol. i. chapters 18 and 19.

ing indications of ancient land surfaces now situated at great depths. It is more than probable that the amount of deposits, so far as it has been proved by borings, represents but a moderate proportion of their entire thickness.

Beyond the alluvial plains or deltas, estuaries or bays are very generally formed, being the extensions or prolongations of depressed valleys, into which sea-water enters. Rivers bring down an amount of debris immensely greater than can be disposed of by their overflow during floods upon deltoid plains. The amount removed, as indicated by the spaces left between the flanks of valleys, and carried into the sea, would, if there were no subsidence, form very extensive plains where there is now sea, and would extend in some cases to hundreds, it may be even to thousands of miles beyond the present deltas; whereas, notwithstanding the great accumulations, deltas are by subsidence transformed into bays, and instead of shallow water the sea becomes, at a few miles from the mouth of the river, unfathomable by the ordinary deep-sea line. Lyell has directed attention to the rapid increase of depth, from shallow water at the mouth of the Mississippi, to 95 fathoms at a distance of 12 miles; 144 fathoms at 20 miles; and 452 fathoms at 52 miles.[1]

The inference to be drawn from the occurrence of subsidence near the mouths of great rivers appears to be, that where there is the greatest amount of accumulation, there subsidence has occurred to the greatest extent, progressing more rapidly than the filling up of the areas by sedimentary deposits.

It is a remarkable coincidence that subsidence of land, when covered with heavy accumulations of perennial snow, should be a phenomenon of general occurrence; it prevailed in the northern hemisphere during former periods over immense districts, but is restricted to a limited area (Greenland) at the present time. All writers on glacial geology recognize this progressive submersion of the land during what is called the 'Glacial Period,' when extensive districts both in Europe and North America, now fertile and luxuriant, were buried under a thick covering of snow; and the bays and seas in their vicinity were packed with icebergs and floating ice; also that a partial re-elevation occurred at its termination. This subsidence may be chiefly ascribed to the weight of the snow heaped upon the land, and in part to the clay which, in muddy streams, issued from beneath the glaciers, and was deposited in a sea covered with bergs and pack-ice bearing rock fragments, which they had carried from many distant localities. The melting of the floating ice caused these erratic pebbles, etc., to be dropped into this clay, and thus become an integral portion of the Boulder-clay. The combined pressure of the snow upon the ground, and the Boulder-clay upon the bed of the sea, weighed down the crust of the earth. It was again raised to a considerable extent upon the return of a more genial climate, which relieved the land of its load of ice and snow.[2]

---

[1] Principles, vol. i. chap. xix.

[2] President's Address, by Charles Ricketts, Proc. Liverpool Geol. Soc. Session 1871-72; also an abstract of the same, GEOL. MAG. Vol. IX. 1872, p. 119.

It appears that Mr. T. F. Jamieson, in 1865, was the first who attributed this depression in different countries during the Glacial period "to the enormous weight of ice thrown upon the land; and considered that the melting of the ice would account for the rising of the land which seems to have followed the decrease of the glaciers."[1]

Professor Shaler, of Harvard College, U. S. A., in 1874, also appears to have arrived independently at the same conclusions respecting the cause of subsidence during the Glacial period; he considers that "we may more reasonably look to the weight of ice accumulated on the continents for the depression of the land areas it occupied than to any other cause."[2]

Similar explanations, in which Mr. Fisher coincides, may account for the subsidence recently occurring in Greenland simultaneously with a rapid increase of accumulated snow; and also for the gradual rise of Scandinavia as a natural result of the recession of glaciers.[3]

In all the older rocks the same fact is evident:—wherever any large amount of strata has been laid down, there has likewise been a persistent depression, which progressed in at least an equal degree with the accumulation. In each individual formation, throughout the whole series, from the Laurentian rocks of Canada, or the Longmynd rocks of Shropshire, up to those now in process of deposition, the record in the one is the record in them all,—*it was formed during a period of subsidence.*

Though there has thus occurred a simultaneous and progressive depression during the deposition of the accumulations constituting stratified rocks, it might be argued that the subsidence has taken place to the same extent over the whole area, and that the strata are thicker in one place than in another simply because their bases have been deposited on surfaces of unequal elevation, that is, on areas consisting of submerged valleys and hills. It requires a certain stratum, forming as it were a base-area, traceable over extensive districts, and situated, when formed at or about the same level, before the relative amount of subsequent deposition and subsidence can be calculated in different portions of the district in question. The Carboniferous formation affords most satisfactory examples for determining the problem.

The Carboniferous Limestone of the north-west of England was formed in a bay separated from another marine area farther south by a narrow isthmus[4] and promontory never submerged, extending, as Professor Jukes pointed out, in "a band of country running east and west across England from Leicestershire, through Warwickshire,

---

[1] History of the last Geological changes in Scotland, by Thomas F. Jamieson, F.G.S., Quart. Journ. Geol. Soc. vol. xxi. p. 178.

[2] Recent Changes on the Coast of Maine, by N. S. Shaler, Memoirs Boston Soc. Nat. Hist. vol. ii.

[3] Cause of the Glacial Period, by Charles Ricketts, Geol. Mag. Dec. II. Vol. II. 1875, p. 573; Rev. O. Fisher, *op. cit.* pp. 223 and 224.

[4] That portion of this isthmus, situated between Coalbrookdale and the Clee Hills, was sixteen miles wide at the termination of the deposition of the Carboniferous Limestone, and was reduced to twelve miles during that of the Millstone Grit.

South Staffordshire, North Shropshire into Montgomeryshire,"[1] and to the mountainous district of North Wales.

The limestone is situated in and fills up valleys formed in Silurian and other rocks, and there has evidently been a progressive depression during the whole period of its formation; from the time when conglomerates and sandstones derived from the neighbourhood were distributed over the bottoms of these valleys,[2] forming the so-called "Upper Old Red Sandstone" of the Survey Maps, though considered by the Members of the Geological staff as forming in such cases the base of the Carboniferous series;[3] and this progressed whilst the flanks of these valleys were being gradually submerged, the basement beds of the limestone being very frequently composed to a great extent of fragments of Silurian rock in a matrix of limestone. This subsidence continued during the whole period in which the strictly marine series, represented by the Carboniferous Limestone, was being deposited; until and beyond the time when that great change occurred, whereby waters, bringing down soluble silicate, mud, sand, and pebbles, were diverted into this area; the distribution of which produced, according to the conditions prevailing in different periods and localities, in the first place siliceous and carbonaceous materials characterizing the Upper Limestone, afterwards the varieties of strata characterizing the Yoredales and Millstone Grit, and at a later period the Coal-measures.

A modern event which must produce effects comparable with,—at least causing as great a contrast as the changes which occurred in the Carboniferous strata above the Limestone,—took place about 1852, when the muddy waters of the Whang-Ho were diverted from the Yellow Sea into the land-locked Gulf of Pe-Che-Lee, the present outlet being removed a distance of not less than 640 miles along the coast-line, around the rocky promontory of Shan-tung (East Mountain).[4]

A very great variation in the *thickness* of the Carboniferous Limestone occurs in different places, and often within very short distances. In the Coalbrookdale district the southern boundary of this formation extends no farther than Little Wenlock, near which village, at Oldfield Quarry, it is 25 feet thick; and a little further northward, at Steeraway, it is 40 feet,[5] but does not exceed 100 feet. It is evident the Carboniferous Sea did not extend over the Silurian rocks to the south, or over those of the Longmynd towards the west; for any strata resting upon them and belonging to that era are referred to the Coal-measure series.

---

[1] Memoirs of the Geological Survey, The South Staffordshire Coal-field; by J. Beete Jukes, F.R.S., p. xii. See also Jukes's Manual of Geology, second edition, p. 518.

[2] Professor J. Phillips recognized that "they were confined to *valleys* in the slate formation, and never follow that rock to its escarpments on high ground."—Geology of Yorkshire, part ii., p. 13.

[3] Mem. Geol. Survey, Geology of Kendal, etc., W. T. Aveline, F.G.S., p. 14; [Prof.] T. McK. Hughes, F.S.A., p. 15; of Kirkby Lonsdale [Prof.] Hughes, p. 16. On the Carboniferous Conglomerates of the Basin of the Eden, by J. G. Goodchild, Quart. Journ. Geol. Soc. vol. xxx. p. 396.

[4] The Double Delta of the Whang-Ho, by Samuel Mossman, Geographical Magazine, vol. v. p. 92.

[5] Geological Survey, Vertical Sections, No. 23.

At Llanymynech, 25 miles north-west of Coalbrookdale, the nearest locality where the Carboniferous Limestone now exists, the precipitous escarpment of Llanymynech Hill rises from a basement of Wenlock shale. Mr. G. H. Morton estimates the thickness of this mass of limestone at 450 feet.[1] This gets thinner towards the north, and at Grug-fryn, nine miles distant, it exists along such a narrow space, resting on Wenlock shale and having sandstone above, that the limestone seems to be not more than 100 feet, or perhaps only 50 feet in thickness.[2]

Near Llangollen, where it overlies beds of sandstone and conglomerate, the Carboniferous basement beds previously alluded to, the limestone forms the magnificent escarpment of the Eglwyseg ridge, and is exposed throughout its whole extent. Its entire thickness according to Mr. Morton, is 1200 feet. This forms a remarkable contrast to the exposure on the opposite bank of the River Dee. Within a distance of four miles, at Fron-y-Cysyllte, where the limestone rests on Wenlock shale, there are wanting no less than 873 feet of the lower strata as developed in the Eglwyseg ridge.[3]

In North Derbyshire near Buxton the thickness of the Carboniferous Limestone has been ascertained to the amount of 1580 feet;[4] but it may be considerably more, for the base can nowhere be determined. Its thickness diminishes towards the north. From nine to twelve miles north-east of Settle, "in the vicinity of Arncliffe and Kettlewell, it is probably not less than 1000 feet thick." To the west of Arncliffe six and twelve miles respectively, "under Penigent and Ingleborough it is from 400 to 600 feet thick, and along the Pennine chain from Kirkby Stephen northward a less thickness may be assigned to it."[5]

Judging from such facts as these, there can be no question that the Carboniferous Limestone has been deposited on surfaces of unequal elevation, in valleys and gorges excavated in the older rocks, and that it has been almost throughout its whole extent precipitated slowly and equally, or been otherwise derived from the waters of the sea. The variation in thickness in different localities is very greatly owing to its having been deposited in the vacant spaces which formed these pre-Carboniferous valleys; at all events the evidence by itself is not sufficiently conclusive to decide that, though the accumulation has been greater in one place than in another, therefore the subsidence has been caused by this increase of pressure.

Though the subsidence has been almost entirely continuous during the whole period of the deposition of the limestone, the sea-bed formed was at no time situated at any great depth, for the valves of Mollusks are frequently separated, and the stems and joints of

---

[1] The Carboniferous Limestone and Cefn-y-fedw Sandstone between Llanymynech and Minera, by G. H. Morton, F.G.S., p. 122.

[2] Morton *op. cit.*, p. 81.

[3] Morton, *op. cit.* pp. 39 and 75.

[4] Mem. Geol. Survey, North Derbyshire, p. 18.

[5] Geology of Yorkshire, by John Phillips, F.R.S., part ii. p. 176.

Encrinites have been washed from each other, as by the action of waves or currents. The water therefore having been shallow, a sufficiently correct base-line is afforded to determine the effects produced by the inundation of this submarine plain by large accumulations (derived from distant sources) which constitute the later Carboniferous rocks, whether a greater or less amount of subsidence occurred locally according to the amount deposited.

In the Coalbrookdale district the thickness of the Millstone Grit, where it lies upon the Limestone at Steeraway, is 80 feet;[1] a little beyond it rests upon Upper Silurian strata; whilst six miles further towards the south none has ever existed, the Coal-measures lying immediately upon Silurian rocks. At Llangollen according to Mr. Morton it increases in thickness to 723 feet.[2] Including with it the Yoredales, it extends in North Derbyshire to more than 3000 feet, with a greatly varying thickness, being of that amount near Sheffield, but it is only 1500 feet near Belper, a distance of less than 30 miles.[3] Beds of Coal occasionally recurring in these strata indicate low-lying land surfaces, posterior to the formation of which there has occurred subsidence with the accumulation many times greater in extent than its whole thickness near the southern margin.

Similar variation in the thickness of deposits occurs also in the Coal formation. Coalbrookdale again affords an example where the accumulations and the changes of level are small compared with other districts; probably because it was situated at a distance from the sources from which the detritus was conveyed, and therefore could not receive the same amount of deposit. The strata in which the profitable beds of coal are situated range from "Little Flint Coal," situated immediately above the "Farewell Rock" (Millstone Grit) to the "Top Coal," and amount to only 180 feet; the gross average thickness of the beds of coal being about 40 feet,[4] that of the beds of workable coal according to Professor Hull 27 feet; the entire thickness of the Coal-measures amounts to 1200 feet.[5] In Denbighshire the Middle Coal-measures, the only ones worked, have a thickness of 800 feet, with from 27 to 30 feet of workable coal. The Lower Measures amount to 1000 feet, with several coal-seams varying from two to three feet. The aggregate thickness of these Coal-measures is about 3000 feet.[6] Again a very great increase is observed in the Coal-measures of the Lancashire district, where, including the Gannister beds, they attain a maximum thickness of 7300 feet.[7]

Taking Leicestershire as a starting-point, the different series of Upper Carboniferous strata attain a very moderate thickness; but a great and progressive increase occurs when passing thence in a north-westerly direction to North Lancashire. Professor Hull has demonstrated this in the following Table of

---

[1] Geological Survey, Vertical Sections, No. 23.

[2] Under the local definition of Cefn-y-Fedw Sandstone, *op. cit.* p. 51.

[3] Fig. 37, Comparative Sections of the Millstone Grit and Yoredale Rocks, Mem. Geol. Survey, North Derbyshire, p. 139.

[4] Geological Survey, Vertical Sections, No. 23.

[5] The Coalfields of Great Britain, by Edward Hull, F.G.S., second edition, p. 96.

[6] Hull, *op. cit.* p. 99.

[7] Hull, *op. cit.* p. 123.

"Comparative Vertical Sections of the Carboniferous Strata from North Lancashire to Leicestershire.

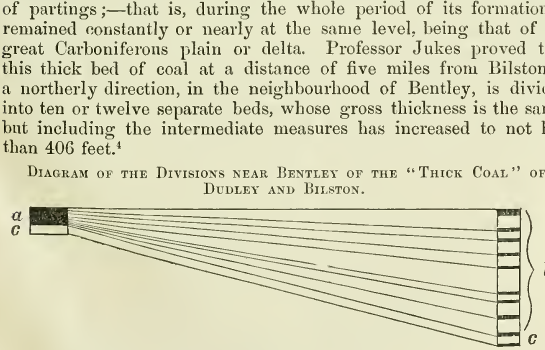
N.N.W. S.S.E.

	Burnley district.	Mottram district.	North Staffordshire.	Leicestershire.
Coal-measures	8460	7635	6000	3000
Millstone Grit	5500	2500	500	50
Yoredales	4675	2000	2300	50
	18,635	12,135	8800	3100."

Commenting on the above sections, Professor Hull remarks, that "it will be observed the beds which attained so prodigious a development in North Lancashire dwindled down to one-sixth of their volume in Liecestershire."[1] The Coal series varies considerably in limited areas in different localities, and there is in Lancashire a general increase of thickness of the sedimentary materials, such as sandstones and shales, towards the N.N.W. Thus the *same* coal-seams are farther apart at St. Helens than at Prescot, and at Wigan than at St. Helens.[2] This difference in the thickness of the Coal-measures occurring within restricted areas has been confirmed by Messrs. De Rance and Strahan, who prove the amount between certain identical beds of coal to be one-third greater at Standish, near Wigan, than at Prescot, an interval of 13 miles.[3]

A most remarkable example of increase in the sedimentary strata occurs in the "Thick" or "Ten Yard" coal of Dudley, which in the southern portion is thirty feet thick, having only two to four feet of partings;—that is, during the whole period of its formation it remained constantly or nearly at the same level, being that of the great Carboniferous plain or delta. Professor Jukes proved that this thick bed of coal at a distance of five miles from Bilston in a northerly direction, in the neighbourhood of Bentley, is divided into ten or twelve separate beds, whose gross thickness is the same, but including the intermediate measures has increased to not less than 406 feet.[4]

Diagram of the Divisions near Bentley of the "Thick Coal" of Dudley and Bilston.



a. Thick Coal at Bilston, 30 feet.
b. Divisions of same at Bentley, 406 feet.
c. Heathen Coal.
Length of Section 5 miles. *Altered from Prof. Jukes.*

---

[1] Q. J. G. S. vol. xxiv. p. 322.

[2] Hull, Coal-fields of Great Britain, p. 123.

[3] Geological Survey, Vertical Sections, No. 61.

[4] Memoirs of the Geological Survey, The South Staffordshire Coal-field, by J. Beete Jukes, F.R.S., p. 25, etc.

Conclusion.—From all these facts it may safely be inferred, wherever there has been a great accumulation, there also has supervened a great amount of depression. Such is the record of the present and every geological era. There must needs be a cause for the simultaneous occurrence of these phenomena being thus universal, inseparable, and in about the same relative proportion. As depression could only permit and by no possibility cause accumulation, the only reasonable explanation is that accumulation over considerable areas is, through the pressure exerted by its weight, the true cause of subsidence. This presupposes a comparatively thin crust to the earth resting upon a fluid or semifluid substratum.

If subsidence occurs in one place, there must, to maintain the equilibrium, be elevation in another. Some examples might be adduced, both in former geological periods and also at present, where elevation has ensued without any reasonable evidence that there has been a local withdrawal of pressure. Elevation would more certainly supervene upon the removal of pressure, and probably occur to a greater extent in the locality whence the detritus has been removed the transfer of which has caused subsidence.

Reference has already been made to the results subsequent to the dissolution of the snow which, during the Glacial period, enveloped the British Isles, Northern Europe, and North America. The re-elevation of the land to a certain height was ascribed to the removal of the pressure by the melting of this load of ice and snow; but in consequence of the accumulation of Boulder-clay which remained, it was not raised to so great an extent as before the submergence. The present gradual rise of the land in Norway and Spitzbergen may also be attributed to the partial removal of once greatly augmented snow-fields.

The immense amount of material removed, and the depth and width of valleys formed, indicate, not only the erosion to which strata have been subjected, but likewise that there has been a rising of the land to expose it to the action of subaerial agencies. If the land sinks as a consequence of the deposition of strata, there will be little difficulty in attributing upheaval to the effects of denudation, when the many thousands of feet of strata which have been removed are taken into consideration. The enormous amount of denudation to which Palæozoic strata in South and North Wales have been subjected was made apparent in the well-known sections by (Sir) A. C. Ramsay, in which the mass of material displaced has been illustrated by contour lines,[1] and may be recognized as having taken place to a greater or less extent in all the older rocks.

Captain C. E. Dutton states that "those areas in the Colorado district which have been uplifted most have been most denuded; he thinks we ought to turn the statement round and say that those regions which have suffered the greatest amount of denudation have been elevated the most; thereby assuming the removal of the strata as the cause and the uplifting as the effect."[2]

---

[1] Memoirs of the Geological Survey, vol. i. plates 4 and 5, vol. iii. plate 28. Referred to by Fisher, *op. cit.* p. 222.

[2] The Geological History of the Colorado River, Nature, vol. xix. 1879, p. 251.

An examination of hilly districts demonstrates that Captain Dutton's remarks have a general application in different areas in our own country. Where denudation has been greatest, elevation prevails to the greatest extent, and the oldest deposits not unfrequently form the highest ground; or hills, sculptured during a previous geological era, and subsequently depressed beneath accumulated strata, have again risen as these deposits have been removed, and the former crest stands conspicuous as the summit of a mountain.

In North Derbyshire, near Buxton, the highest portion of the Carboniferous Limestone, forming the "water parting" between the east and west of England, is 1500 feet above the sea-level, and is surmounted in the neighbourhood by ridges only, composed of Millstone Grit, some of which run up to 1800 or even to 2000 feet.[1] The whole thickness of later Carboniferous strata,—the Yoredales, Millstone Grit and Coal-measures, amounting to more than 5000 feet, —has been removed by denudation; but on every side such strata dip away from the dome-shaped mass to lesser elevations.

In the district of Craven in Yorkshire the Carboniferous Limestone rests horizontally on eroded edges of greatly contorted Silurian strata which, at the commencement of its formation, were situated at the then sea-level, their fragments, consisting of large blocks (some being 3 or even 5 feet in their longest diameter, with pebbles and smaller particles entering largely into the composition of the lower beds of limestone.[2]

The curvatures in the Silurian rocks having been formed previous to the commencement of the deposition of the limestone, it is evident the agency which caused them has had no influence in producing the present elevation of the land. The limestone, which is 600 feet thick, continued to subside under the accumulation of later Carboniferous strata, of the Yoredales, Millstone Grit, and Coal-measures, which has been estimated to reach a depth of at least 3500 feet. North of the Great Craven fault, not only have all these strata been removed by denudation, but the Carboniferous Limestone forms a plateau, now raised to about 1400 feet above the sea-level; the elevated ridges resting conformably upon it; such as Penigent (2273 feet), Ingleborough (2375 feet), and Whernside (2414 feet), being mere remnants of strata, formed subsequently to the limestone, which have resisted destruction.

Another illustration may be given of subsidence occurring whilst deposition was in progress, and of rising of the land during denudation. The metamorphic rocks which constitute the Malvern range were sculptured nearly to their present contour, but formed an island during the deposition of Upper Silurian strata; this was demonstrated by Miss A. Phillips, whose discovery proved that their base consisted of "a conglomerate full of Silurian shells, the pebbles being fragments of the rock-masses of the Malvern Hills."[3]

---

[1] Memoirs of the Geological Survey, North Derbyshire, p. 2.

[2] On a group of Slate Rocks, between the Rivers Lune and Wharfe, by John Phillips, F.G.S., Trans. Geol. Soc. second series, vol. iii. pp. 10 and 13.

[3] Memoirs of the Geological Survey, The Malvern Hills, etc., by John Phillips, F.R.S., vol. ii. part 1, p. 66.

Deposition progressed, and the land must have sunk to a great extent to permit the formation of the Upper Silurian and Old Red Sandstone strata, so greatly developed in the neighbourhood. But these, in a much contorted state, were again uplifted, and at the same time greatly denuded; but the elevation or formation of the hill is in nowise dependent on the foldings of these rocks, for the ridge again stood forth as an island from what may have been a near approach to the sea-level of the time, when, upon the upturned and eroded edges of these Silurian and other rocks, conglomeratic breccia,[1] and sandstones were deposited during the New Red Sandstone period, depression of the land occurring simultaneously. The land has since undergone a great amount of denudation, and the district has been raised to its present elevation. Such or similar methods of interpretation appear to be generally applicable in assigning a cause for the formation of mountains or other elevated ground.

The cause more generally assigned for subsidence of the crust of the earth is secular cooling of its mass. This cannot also account for the accumulations which so constantly accompany it, nor is it conceivable that the continuance of the same agency would occasion its re-elevation. If in any case depression has been due to such influence, it may be looked for in the extreme depths of the ocean, where the constant temperature nearly approaches the freezing-point; certainly not in the Arctic regions, where the mean annual temperature is very much lower; for though Greenland is sinking, Norway and Spitzbergen are rising; so also are extensive districts near to or within the Arctic circle—Labrador, Hudson's Bay, the Arctic Archipelago and the shores of Behring's Straits[2]—affording unmistakable testimony to elevation of the land within a recent period; in some cases affording evidence that such is now in progress. It has recently been estimated that the shores of Hudson's Bay have risen in places from five to ten feet within the century.[3]

Near the mouths of large rivers, in deltas and in bays, and during former geological periods, where strata have been deposited, depression has been persistent, even though such a thick covering has been overlaid as would retain the central heat and exclude the external cold.

Deposition and subsidence having been constant and contemporaneous during all geological periods, the phenomena can only be attributed to and associated together as cause and effect. Whether it be strata laid down in the sea, those forming deltas near the mouths of large rivers, or a thick covering of snow that has fallen on the land, the accumulated weight presses down the crust of the earth.

It is also nearly as certain that elevation of continents is to be attributed to denudation to which the land has been subjected, causing a relief of pressure, whether by the disintegration of the rocky mass or by dissolution of glaciers; in the former case it might be further assisted by the transfer of the molten substratum as a consequence of depression in another area.

---

[1] Haffield Conglomerate of Phillips.

[2] Recent Elevation of the Earth's Surface in the Northern Circumpolar Region, by Henry H. Howorth, Arctic Manual, 1875, Reprinted from the Journal of the Royal Geographical Society, vol. xliii. 1873.

[3] The *Times*, Jan. 14, 1880.

In an address delivered at Sheffield more than three years ago, having reference to the Coal formation, it was remarked that "the more the subject is considered, the more astonishing does it become for the regularity of the subsidence; and its amount must have kept pace with the thickness of the accumulating deposits;"[1] but these concurrent phenomena demand more than wonder, they require serious and careful attention such as is yet to be bestowed upon them. This is the more necessary, as in them may be found the great motive power which not only produces changes of level in the earth's crust, but also permits and induces many other alterations in its physical condition.

Mr. H. B. Woodward, F.G.S., quite recently, in the Transactions of the Norfolk and Norwich Naturalists' Society,[2] has specially alluded to my opinions respecting the dependence of upheaval and of subsidence upon the denudation and the deposition of materials; and has also re-directed attention to the subject in a favourable manner by a letter in the Geological Magazine.[3] Having formerly (1873) criticized my views adversely, these recognitions of them must be considered to be greatly enhanced in value.

---

[1] President's Address to Section C, at Sheffield, by Professor P. Martin Duncan, F.R.S., British Association Report, 1879, p. 330.

[2] The Scenery of Norfolk, vol. iii. p. 460.

[3] Dec. II. Vol. X. p. 93, 1883.

Stephen Austin and Sons, Printers, Hertford.